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AERODYNAMICS OF A 0.60 CALIBER ELECTROMAGNETIC PROJECTILE

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APRIL 1991

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13. ABSTRACT *(Maximum 200 words)*

Spark photography range tests of a 0.60 caliber electromagnetic projectile were conducted to determine the aerodynamic characteristics at supersonic velocities. The design demonstrated adequate stability and typical drag characteristics. The effect of an asymmetric base geometry on the location of the aerodynamic center of pressure is also shown.

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INTRODUCTION

In December 1989 a meeting between Armament Research Development and Engineering Center and Ballistic Research Laboratory (BRL) personnel reviewed the progress of the 0.60 caliber electromagnetic (EM) projectile. The conclusion of the meeting was that a spark range test should precede EM firings to be conducted at the University of Texas (UT) in June of 1990. Since the modest small caliber range facilities bordered the machine snop area at UT, it was considered important to determine the behavior of the projectile beforehand. This report details the aeroballistic behavior of the EM projectile as determined from the spark range test at the BRL Aerodynamics Range. [1]

BACKGROUND

A sketch of the 0.60 caliber projectile tested is shown in Figure 1. The tungsten nose of the projectile is a Sears-Haack shape. This nose section threads into the aluminum afterbody. The afterbody, flare, and armature are one piece and form the remainder of the projectile. The exterior grooves, shown near the nose afterbody joint, allow the afterbody to support a torlon bore-rider (not shown). Small fins, dubbed "finlets", are shown on the armature portion of the projectile. The finlets are roughly an eighth of a centimeter high and two and one half centimeters long. Their purpose is to add pitch-plane stability. A slot extending from the rear of the projectile to the rear of the flare is also shown. The slot's purpose is electromagnetic in nature. Finally, the rear view shows a noncircular base that attempts to maximize the conductivity to armature weight ratio.

TEST RESULTS

Table 1 contains salient projectile physical characteristics. The two transverse moments (I_{yy} and I_{zz} in the pitch and yaw planes respectively) and axial moment of inertia differ widely due to the projectile's mass distribution. The ratios of the transverse moments to the axial are roughly five times larger than a typical round. The following table, Table 2, is a tabulation of the aeroballistic coefficient values obtained from the test.

Interior ballistic modelling indicated that the projectile survived acceleration loads greater than 100,000 g's. This information indicated UT's standard safety measures would be appropriate when testing.

A tricyclic reduction was employed in determining the projectile characteristics.[2] The tricyclic reduction is normally used when a projectile asymmetry exists. For the reduction a third, constant magnitude, modal arm, K_3, is assumed in addition to the two modal arms of the epicyclic motion. The size of this arm depends on the reduction data, but it

[1] Braun, W.F. "The Free Flight Aerodynamics Range," U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, BRL Report No. 1048, August 1958. (AD 202249)

[2] Murphy, C.H.," Free Flight Motion of Symmetric Missiles" U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, BRL Report No. 1216 July 1963. (AD 442757)

is typically smaller than the other two epicyclic modal arms.

Some criteria and general engineering rules-of-thumb are applied when examining the data in the reduction process. Firstly, the data from the rounds with the fewest number of range stations are examined closely. Another standard is that the K_j arm must be greater than 3 times the fitting error.[3] The $C_{M_{q}} + C_{M_{\alpha_0}}$ value in Table ' for Round 19457 did not pass this criterion, and is therefore absent. Absolute errors as a percentage of the coefficient values are listed in the reduction printout.

Drag Coefficient

The drag coefficient for the 0.60 caliber projectile is assumed to be of the form:

$$C_D = C_{D_0} + C_{D_{\delta^2}}\delta^2 + ... \qquad (1)$$

where C_D is the range value of the drag coefficient, C_{D_0} the zero yaw drag coefficient, $C_{D_{\delta^2}}$, the quartic yaw drag coefficient, and δ^2, the yaw squared.[4] The zero yaw drag coefficient data, fit by a least squares curve, displayed in Figure 2, show a typical supersonic decline with increasing Mach (M) number (the quartic yaw drag contribution is small compared to C_{D_0}). The curve fit is done for rounds with similar values of $C_{D_{\delta^2}}$ and excludes rounds 19452 and 19453

The 0.60 caliber EM projectile drag coefficient is roughly 10% smaller in comparison to INTERACT predictions for a projectile with a full flare and circular base at $M = 4$ to 5.[5] The effect of the finlets on the drag coefficient is probably on the order of 5-10%. [6]

Lift Coefficient

Similarly the lift coefficient for zero yaw, $C_{L_{\alpha_0}}$, as a function of Mach number is shown in Figure 3. The graph illustrates a small variation from approximately M=2 to 5.

Static Moment Coefficient

The variation in static moment coefficient for zero yaw, $C_{M_{\alpha_0}}$, with respect to Mach number is shown in Figure 4. This graph indicates that the projectile has adequate stability in the Mach range depicted.

[3] Ibid.

[4] Murphy, C.H.,"Data Reduction for the Free Flight Spark Ranges," U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground,MD, BRL Report No. 900 February 1954. (AD 035833)

[5] Nusca, M. J."Supersonic/Hypersonic Aerodynamics and Heat Transfer for Projectile Design using Viscous-Inviscid Interaction" BRL-TR-3119, June 1990. (ADA 224354)

[6] Celmins, I."Drag and Stability Tradeoffs for Flare-Stabilized Projectiles," U.S. Army Ballistic Research Laboratory Aberdeen Proving Ground, MD, Paper presented at the 28th Aerospace Sciences meeting, Reno, NV, AIAA Report 90-0065, January 1990.

Center of Pressure of Normal Force

The INTERACT code was also used to assess the effect of the noncircular base. INTERACT predictions and range data for the location of the aerodynamic center of pressure of normal force (CPN) are shown in Figure 5. The CPN is given in calibers measured from the nose. Projectile orientation 1 is where the flat edges are in the yaw plane, while orientation 2 places the projectile's flat edges in the pitch-plane. Range photographs and reductions indicate that a small amount of spin (from 5 to 15 Hz) was produced by the beveled leading edge of the finlet. Since the projectile has some spin, it is assumed that the average of the two predictions models the CPN in flight. Small spin rates (less than 50 Hz) are desirable to reduce the effect of any production asymmetries. The agreement between this average value of CPN and the range data is quite good. The largest difference between the average and the range data curve is less than 10%. The code does not account for the finlets or the slot at the projectile base. Incorporation of these details into the computational model would require significantly more analysis time. For this model, above M=4, the code predicts shock wave detachment at the flare. INTERACT's predictive ability decreases greatly for this condition.

Pitch Damping Moment Coefficient

The pitch damping moment coefficients for zero yaw versus Mach number are shown in Figure 6. The data indicate a strong dependence on Mach number. A weak dependence on yaw exists.

Modal Damping Rates

The complex yaw equation is:

$$\xi = \xi_g + K_1 e^{i\phi_1} + K_2 e^{i\phi_2} \tag{2}$$

where ξ_g is the yaw of repose and

$$K_j = K_{j0} + e^{\lambda_j s}, for j = 1, 2 \tag{3}$$

Negative λ's indicate a decay of the modal arm magnitudes. Figure 7 indicates the trend of λ in the Mach number range examined. Both modes seem to have similar damping rate trends. Two of the rounds used an epicyclic reduction only, Round 19453 and 19457, and achieved results similar in their magnitude and trend to the tricyclic reduction. These rounds' small yawing motion were not fit well using a tricyclic reduction.

Electromagnetic Considerations

Many of the projectile attributes are driven by EM factors. These factors must be addressed if a successful design is to be achieved. They are:

1. The armature must make good electrical contact with the rails and conduct the required current.

2. The projectile should eliminate or at least minimize arcing.

3. The projectile support mechanism must not interfere with current path.

Other considerations such as transient launch stresses due to rapid current rise times are important. This may be primary in the material selection for future afterbody sections. It is hoped a two jointed projectile design, with a tungsten nose and a high strength, light weight afterbody material, may permit higher launch acceleration, further improve stability, and enhance terminal ballistic effects.

CONCLUSIONS

The aerodynamic characteristics of the 0.60 caliber EM round are well behaved in the Mach number range from 1.2 to 5. In addition the projectile survived accelerations in excess of 100,000 g's, and is suitable for testing at the University of Texas range.

The noncircular base has lessened the drag without sacrificing projectile stability. The projectile design represents an efficient combination of aerodynamics and armature requirements.

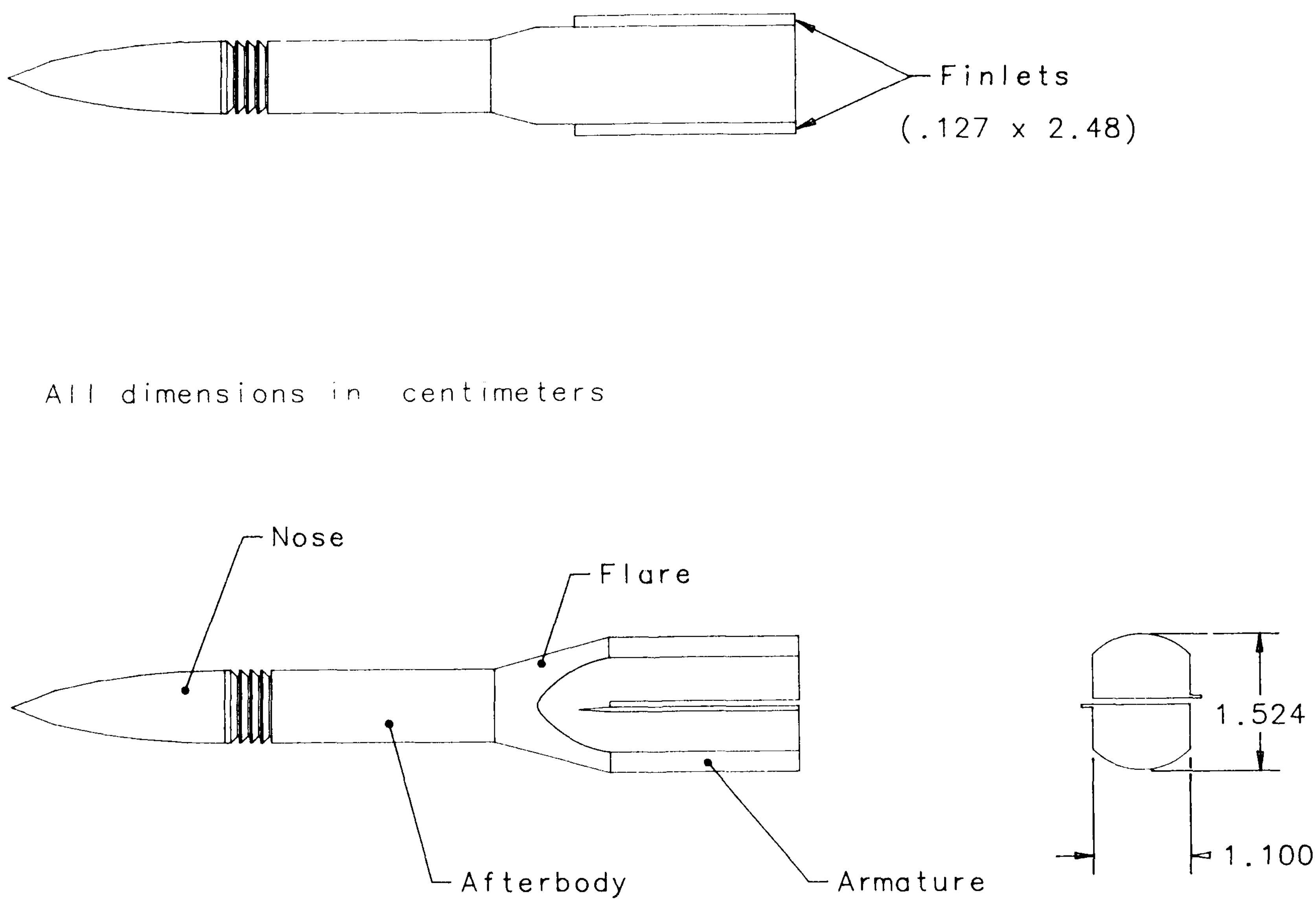

Figure 1. Projectile Configuration.

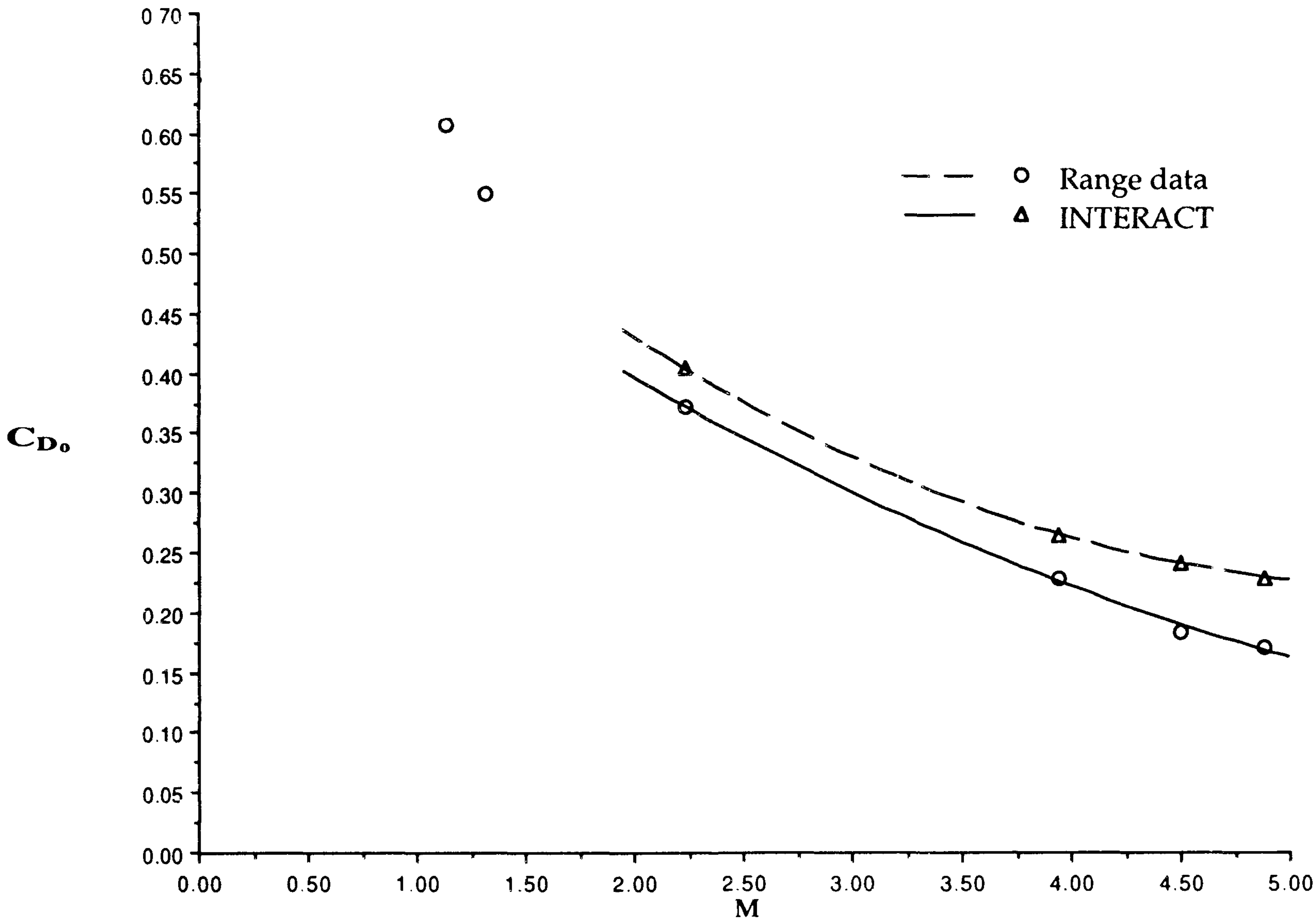

Figure 2. Zero Yaw Drag Coefficient versus Mach Number.

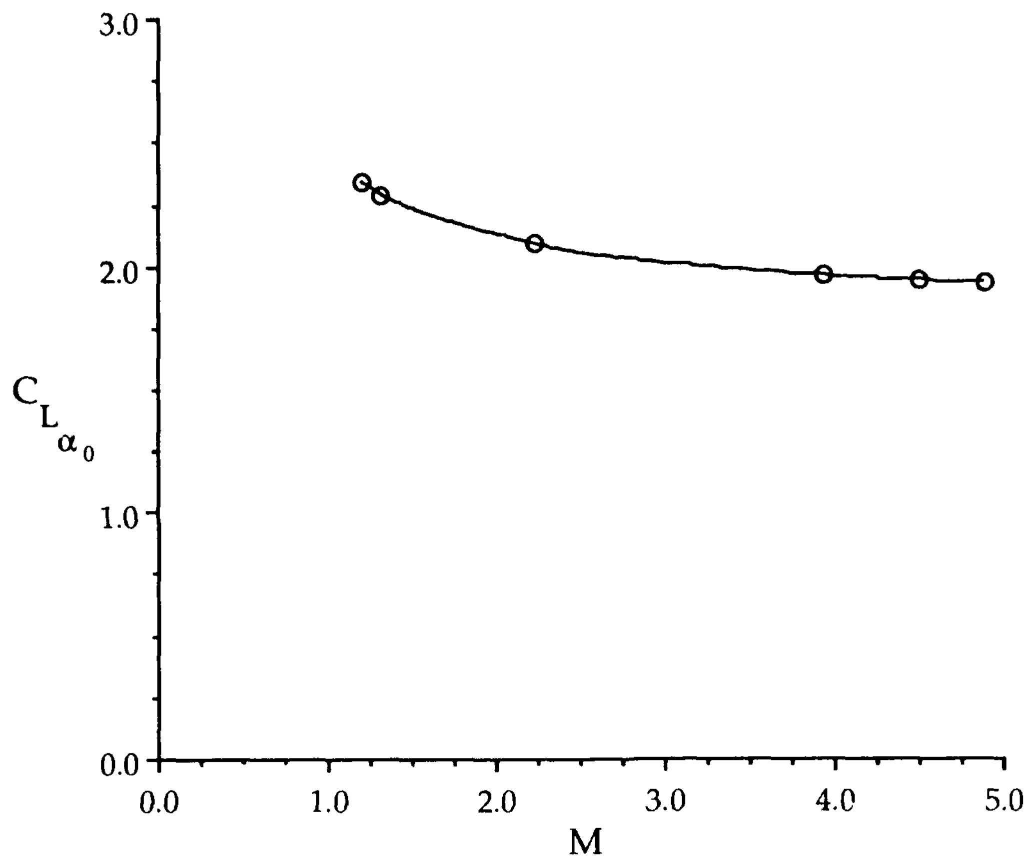

Figure 3. Zero Yaw Lift Coefficient versus Mach Number.

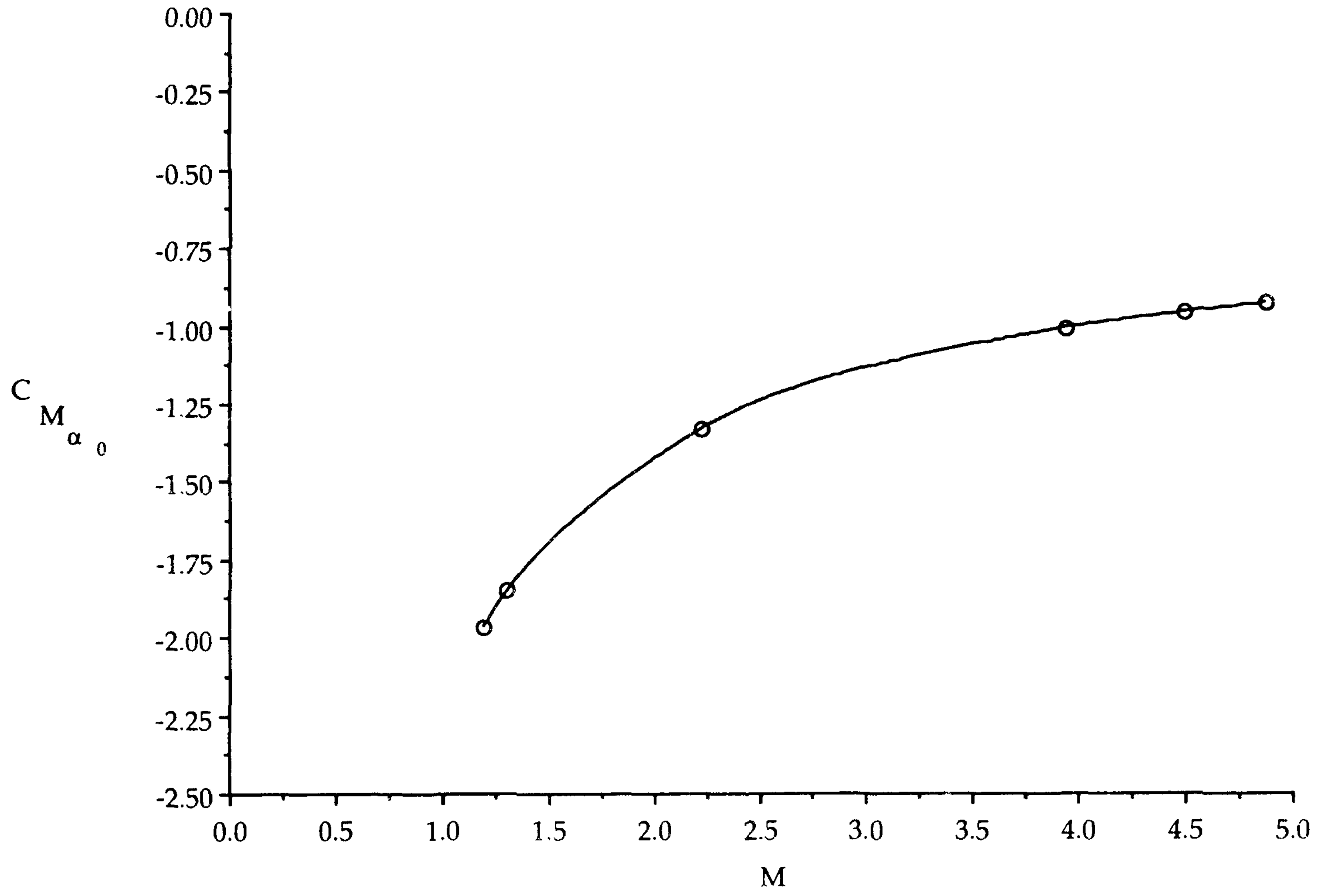

Figure 4. Zero Yaw Static Moment Coefficient versus Mach Number.

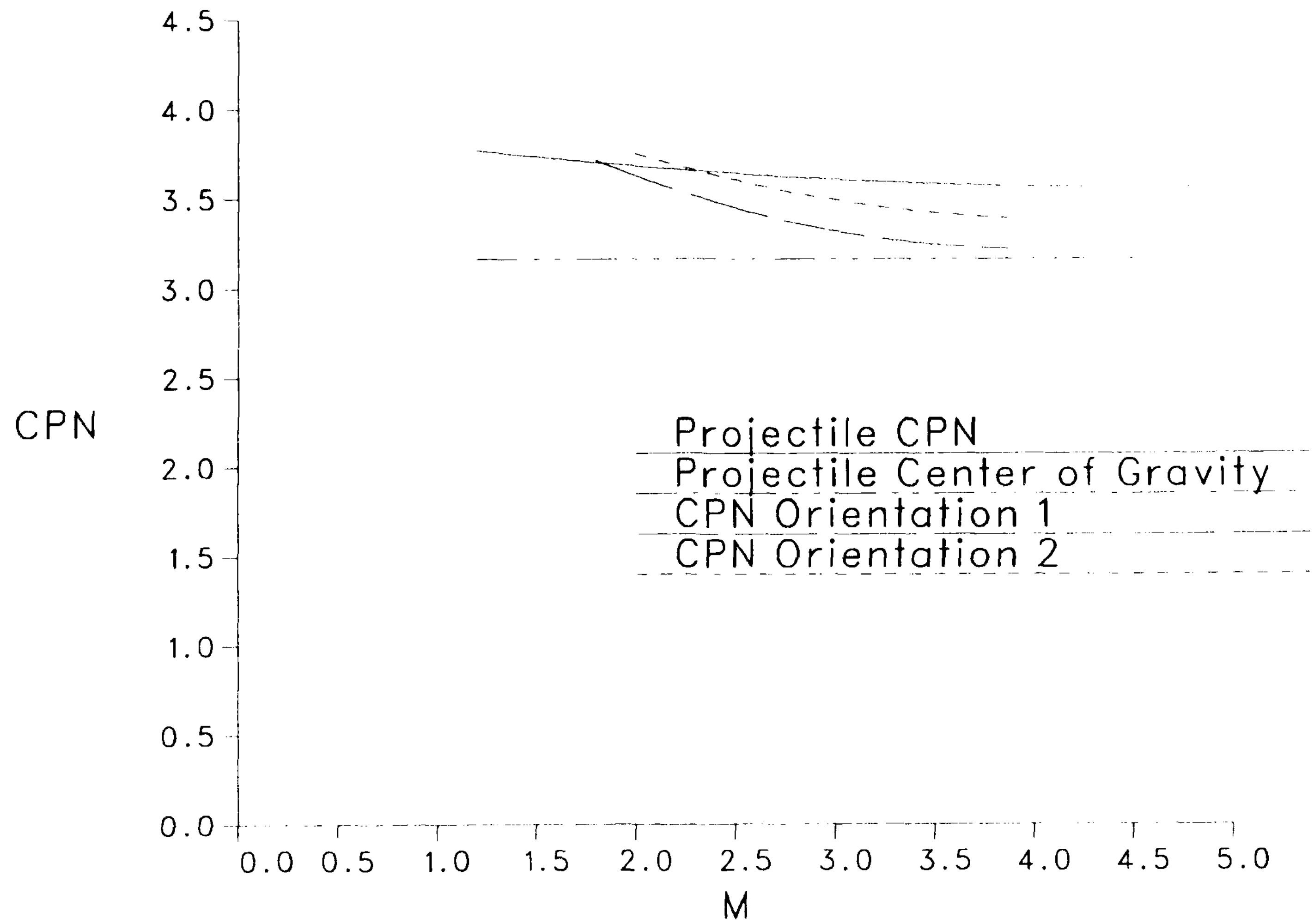

Figure 5. Center of Pressure versus Mach Number.

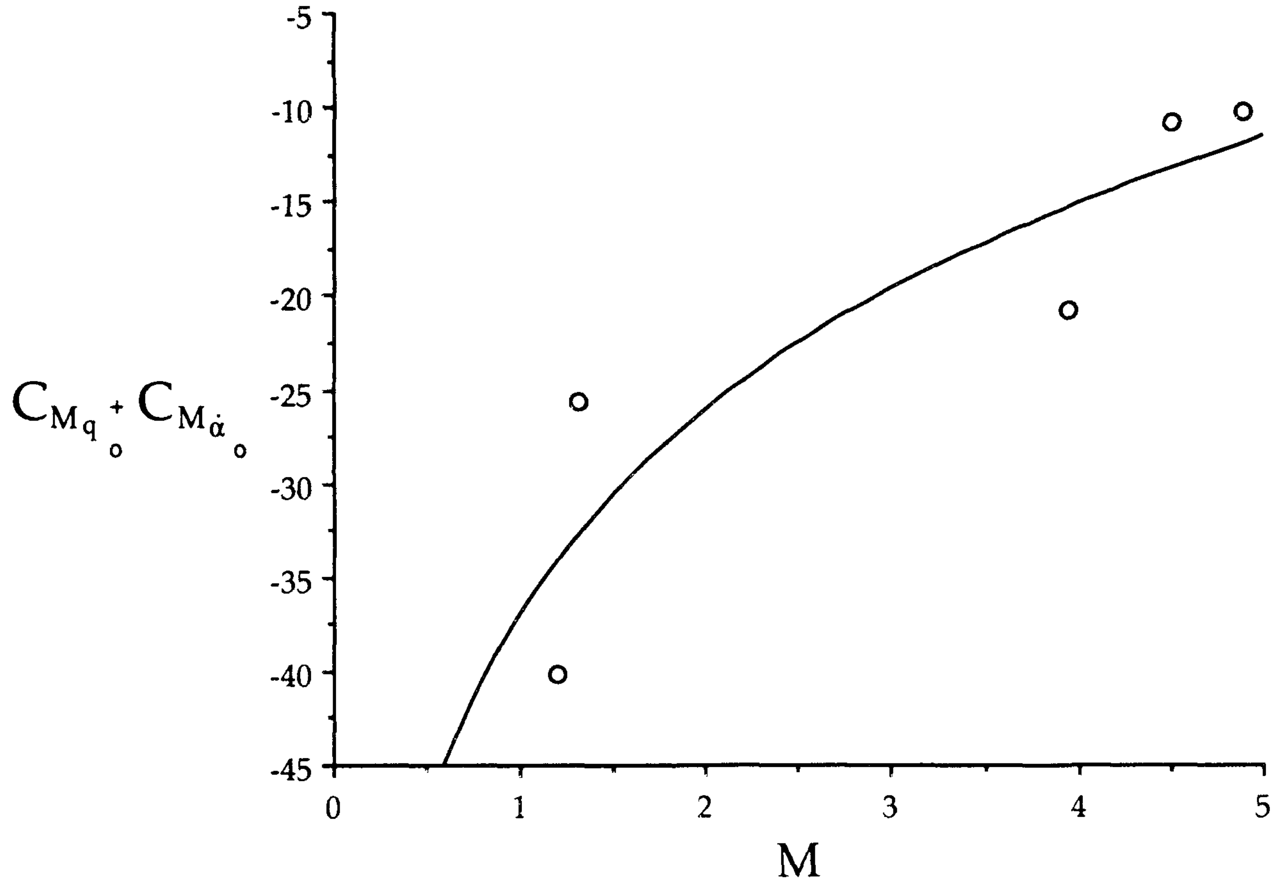

Figure 6. Zero Yaw Pitch Damping Moment Coefficient versus Mach Number.

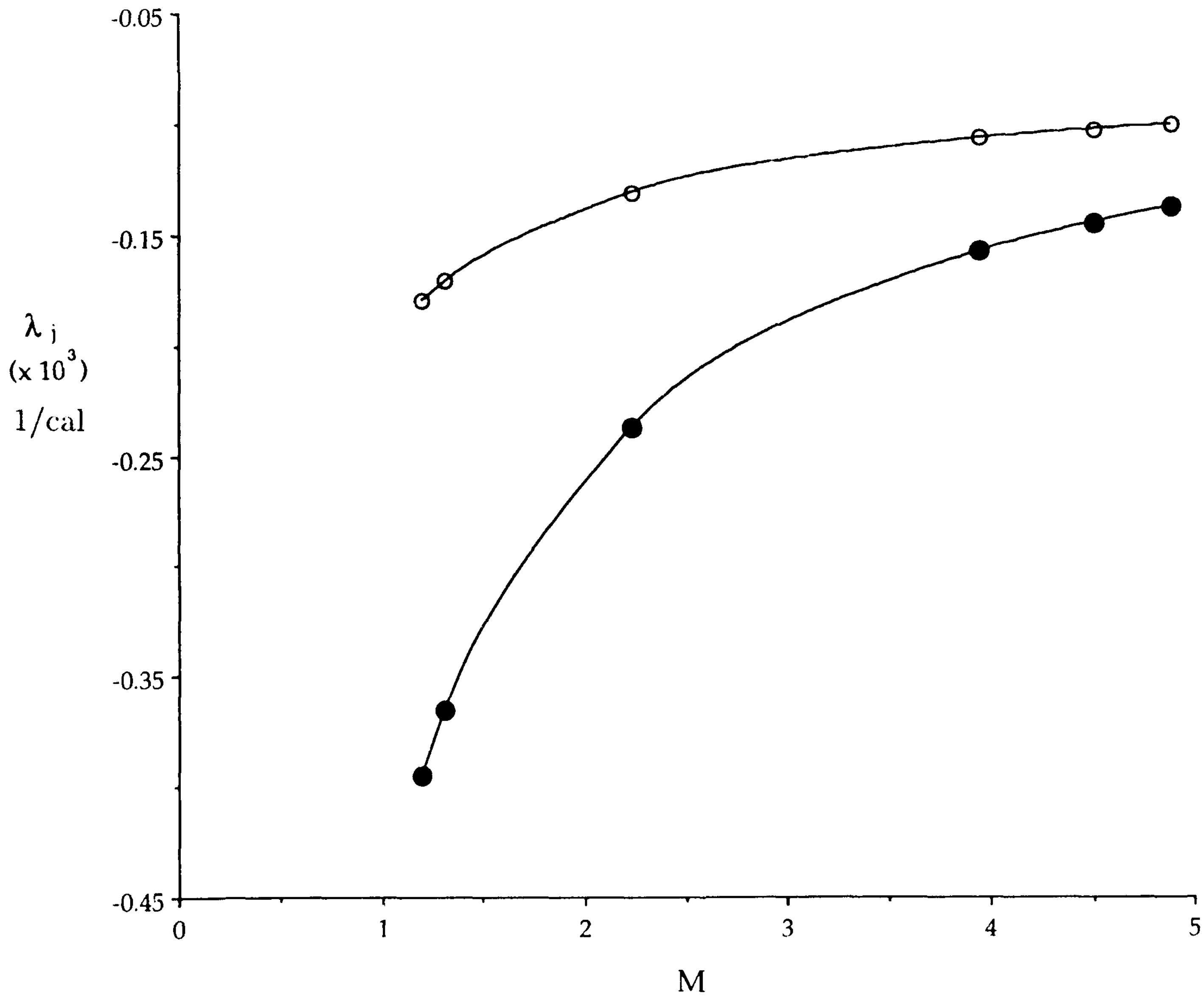

Figure 7. Damping Rate Exponents versus Mach Number.

Table 1. Projectile Physical Characteristics

Reference Diameter	1.524 cm
Center of Gravity	4.318 cm
Length Overall	8.880 cm
Nose Length	2.408 cm
Slot Width	.068 cm
Weight	31.48 grams
Pitch Plane Moment of Inertia	238.46 gram-cm^2
Yaw Plane Moment of Inertia	237.72 gram-cm^2
Axial Moment of Inertia	4.58 gram-cm^2

Table 2. Aerodynamic Coefficients

Round	Mach No.	C_{D_0}	$C_{L_{\alpha_0}}$	$C_{M_{\alpha_0}}$	$C_{M_{q_0}} + C_{M_{\dot{\alpha}_0}}$	$\lambda_1 x 10^3$	$\lambda_2 x 10^3$
19452	1.196	.617	2.34	-1.97	-40.2	-.180	-.395
19453	1.312	.521	2.29	-1.85	-25.7	-.171	-.365
19454	2.237	.395	2.09	-1.33	-20.8	-.131	-.237
19457	3.942	.270	1.96	-1.01	--	-.107	-.158
19458	4.500	.215	1.94	-0.96	-10.8	-.103	-.145
19459	4.884	.197	1.93	-0.93	-10.2	-.101	-.138

LIST OF SYMBOLS

C_D	Drag coefficient
C_{L_α}	Lift coefficient
C_{M_α}	Static moment coefficient
$C_{M_q} + C_{M_{\dot\alpha}}$	Pitch damping moment coefficient
CPN	Center of pressure of normal force in calibers from the nose
g	Earth's gravitational acceleration
Hz	Hertz (cycles/second)
K_j	Modal arm amplitude
M	Mach number
ξ	Complex yaw
λ_j	Exponential damping values
δ	Projectile yaw

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